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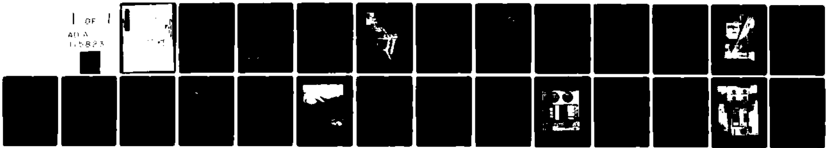

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A brine stratified towing channel has been constructed at NRL as part of the Marine and Environmental Hydrodynamics Laboratory. The channel is 3 ft. deep x 4 ft. wide x 60 ft. long and has clear walls and floors over most of its length. The dual carriage towing system is cable driven from a single variable speed D.C. motor and has a basic speed range of 1 to 24 in/sec. A variety of towing arrangements are available. A semi-automatic stratification system can produce an unlimited range of stable density profiles within the channel.

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CONTENTS

A NEW STRATIFIED TOWING CHANNEL AT NRL

INTRODUCTION

The stratified towing channel shown in Figure 1 and described in this report was constructed as part of the Naval Research Laboratory's expanding basic research programs in fluid mechanics. The facility is part of NRL's Marine and Environmental Hydrodynamics Laboratory [1] where laboratory-scale experimental research for both the Marine Technology Division and the Environmental Science Division has been conducted since 1976. The fluid dynamic research efforts of these divisions range from studies of flow-induced vibrations [2] and wave effects on structures [3,4] to radar oceanography experiments that elucidate the mechanisms of energy transfer between winds and waves [5]. The existing wind-wave channel [1] has been an important asset to these programs and on numerous occasions has been utilized by other programs at NRL and elsewhere. The addition of a medium-sized towing channel with a capability for vertical density stratification became necessary as part of a new research program in the Marine Technology Division concerning large-scale coherent motions in turbulent bluff-body wakes [6]. Benefits to ongoing efforts in the area of fluid-structure interactions were anticipated as well.

The stratified towing channel facility was designed and fabricated as three separate components: the channel, the towing system, and the equipment both for making and for processing brine to provide a wide range of stable stratifications within the channel. The characteristics and the performance of these systems are discussed in the following three sections of the report. A brief description of instrumentation and support equipment which is available at the Marine and Environmental Hydrodynamics Laboratory

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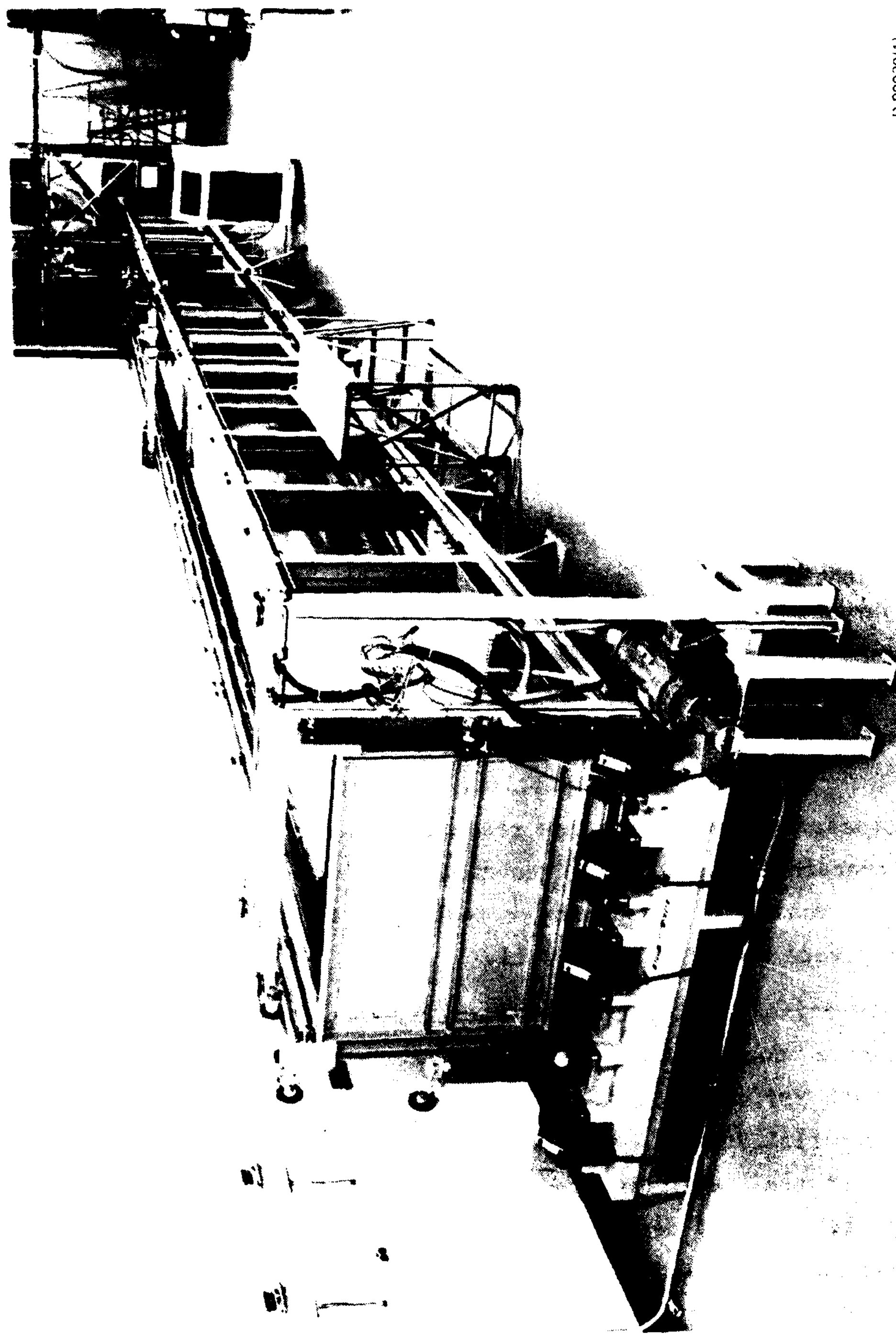

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Fig. 1 — A photograph of the stratified towing channel

is given in section five. A summary of the salient features of the towing channel facility appears in section six and a step-by-step operating description of a typical test cycle is included as an appendix.

THE TOWING CHANNEL

The channel has nominal interior dimensions of 3 ft. in depth, 4 ft in width and 60 ft. in length (approx. 1 m x 1.3 m x 18 m). The basic structure consists of a steel I-beam and angle frame welded together and covered with acrylic panels and stainless steel sheets. The 1/4 in. thick steel panels were employed in the walls and floors of the end sections to provide greater strength and rigidity, to withstand harsher treatment, and to allow mounting of assorted hardware. Each steel end section is 6 ft. long. The walls and floors in the remaining 48 ft. are clear acrylic panels to facilitate observation and flow visualization studies. Some details of the channel construction can be gleaned from the photograph in Figure 1. The 4 in. I-beams were used as vertical and cross-channel members of the framework and are located on 4 ft centers. The I-beam assemblies are joined by assorted steel angles and fastened to the concrete floor at each leg. The framework was welded together in four sections in the shop and transported to the laboratory for final alignment and assembly. The channel bottom is about 18 in. above the laboratory floor to give access for viewing, lighting, and so forth.

The acrylic wall panels are fastened in place along the top and side edges with stainless steel bolts and the floor panels are held by a simple clamping arrangement at the midspan of the I-beam crossmember. The number of rigid attachment points was minimized to allow expansion and contraction of the panels. A 1/16 inch thick rubber pad was installed between the mating surfaces of the acrylic panels and the steel frame to absorb small irregularities at the welded joints. The seams in the acrylic sections of the channel were sealed by a thinned mixture of polyvinyl sulphide caulking while the side panels were pressed against the steel frame with spreaders. The seams in the steel end sections were sealed by welding. The results of these sealing procedures have been satisfactory.

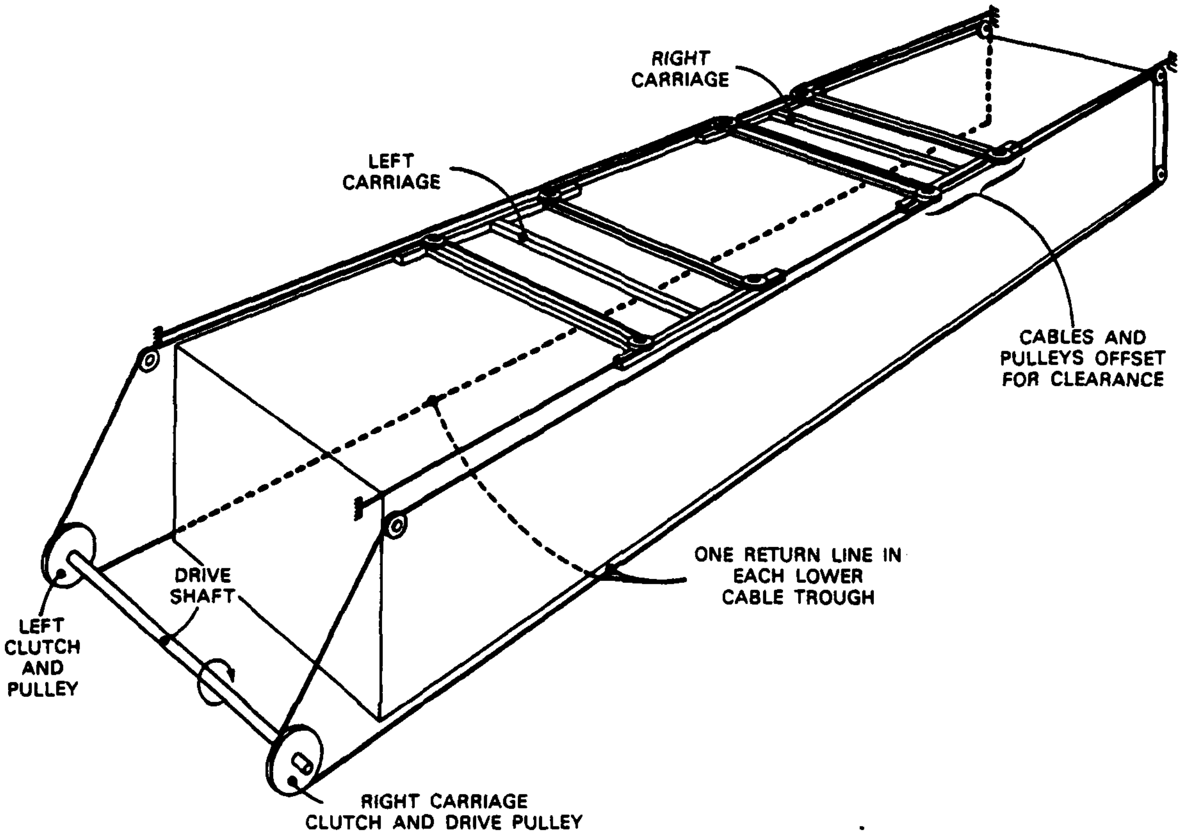

Fig. 2 — A sketch of the major elements and features of the dual carriage towing system

The channel holds nearly 5400 gallons of water and can be filled from the temperature controlled fresh water supply in less than 2 hours. The stratification system takes slightly longer to fill the channel. Both filling modes utilize a distribution manifold along the floor of the channel. This manifold consists of two 1-1/4 inch diameter PVC pipes that run the length of the channel about a 1/4 inch above the floor panels. Each pipe has a row of holes on 2 inch centers along its bottom. The purpose of the manifold is to insure that the brine mixture is delivered almost uniformly over the entire floor of the channel so that vertical mixing is minimized when an increasingly dense mixture is fed to the channel. The maximum water level in the channel is maintained through overflow standpipes at both ends. By opening a valve at each of these locations the channel can be drained in about one hour. The combined time for filling, testing, and draining should easily permit a complete cycle each working day.

THE TOWING SYSTEM

The varied requirements of a basic research program in turbulent wakes together with several cost limitations led to the towing arrangement sketched in Figure 2. The cable drive system is based on a single 3 HP variable speed D.C. motor (Boston Gear Ratiotrol) connected through a gearbox to the driveshaft. Two cable-driven carriages which run on a common set of rails can be individually engaged or disengaged from the driveshaft through electromagnetic clutches. Two additional clutches with cable drive pulleys are available for other modes of towing which may include an overhead line or a submerged tow cable. Some details of this arrangement can be seen in Figure 1. Hardware has been installed to support a submerged towline along the bottom of the channel. The versatility of the system permits one carriage to follow the other at arbitrary distances and provides a wide range of possible towed body mountings, e.g., suspended between a carriage and a submerged towline. The drive cable layout has been likened to older model drafting equipment and was selected to reduce the misalignment of the carriages under eccentric loads.

The speed range of the towing system is about 1 to 24 in./sec. (approx 2 to 60 cm./sec.) and is regulated by tachometer feedback to within ±0.1% of the mean. Large and sudden load changes, such as the abrupt engagement of

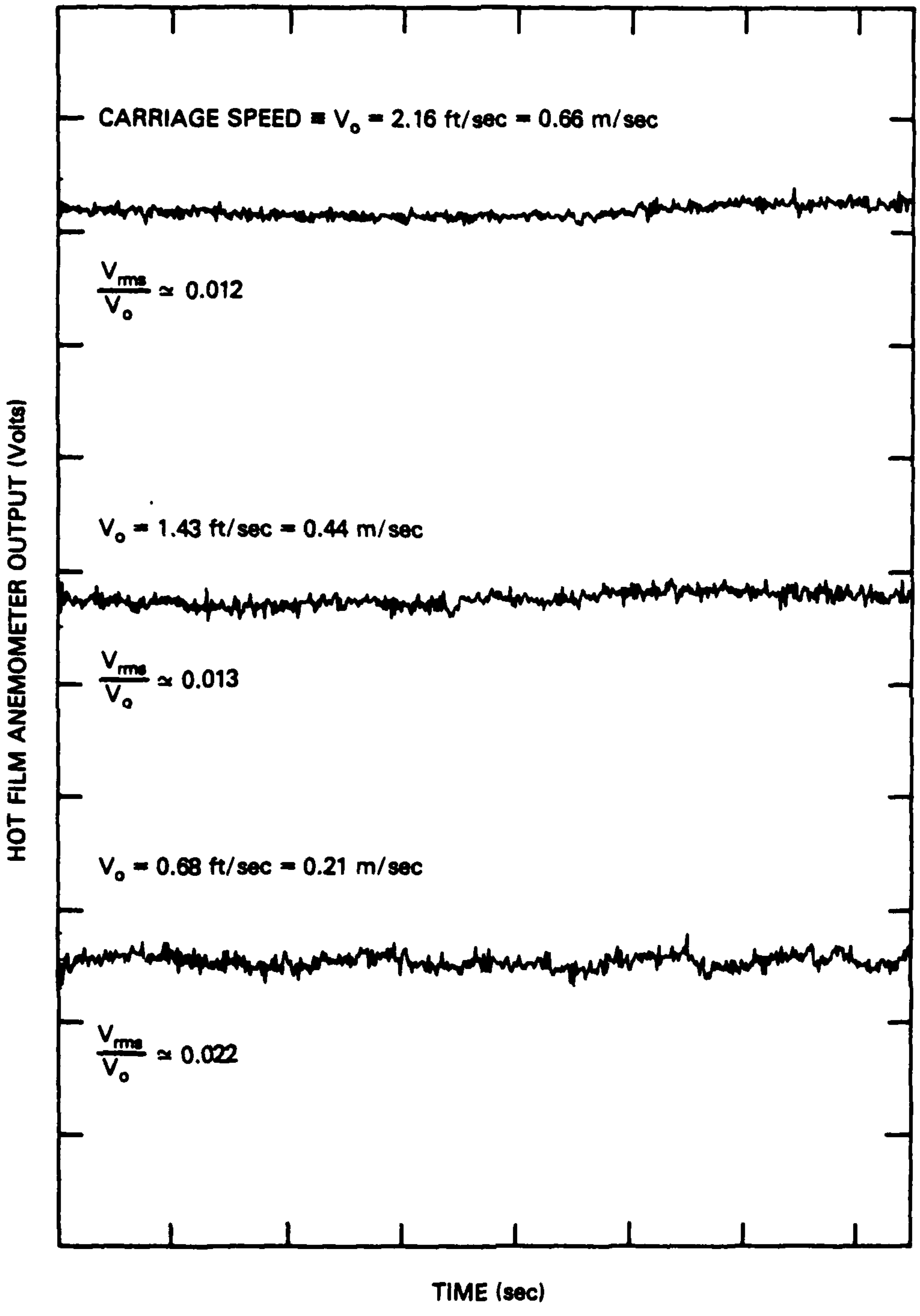

Fig. 3 — The output of a towed hot-film anemometer at three speeds

the second carriage, will produce transients in the tow system speed. The sudden start transients, though small, are troublesome in a stratified environment and should be avoided. Another performance characteristic of the tow system is the level of vibrations present at the carriages. These undesirable vibrations can impart oscillations to the model, to the sensors or to both and in doing so could produce internal waves, wake synchronization effects, and psuedo-turbulence "noise" at the sensors mounted on the carriage. During the initial testing of the facility rather large intermittent vibrations were observed that were later attributed to travelling transverse waves on the drive cables. These disturbances decayed very slowly and upon reaching a carriage imparted significant motions. This source of unwanted motions was greatly reduced by the insertion of damping devices at the cable terminations and by letting the cables become slack enough to rest on the floor of the cable troughs. The remaining vibration levels present a noise threshold for fluid measurement insofar as the vibrations are transmitted to the sensors. This threshold is easily established for a particular sensor and mounting by towing the sensor package through a quiescent channel. Typical results for a hot-wire anemometer towed at three speeds are shown in Figure 3.

THE STRATIFICATION SYSTEM

The purpose of the stratification system is to first prepare brine that is saturated at room temperature and then to mix the saturated brine with fresh water in a sequence of predetermined ratios. The mixture, which starts as completely fresh water, is progressively delivered to the channel with constant or increasing density, i.e., brine content. In this way the mixture entering the bottom of the channel through the inlet manifold always has a density at least as great as the fluid above it. The accurately controlled mixing of brine and fresh water is accomplished by the mixing system shown in Figure 4. The mixing valve (Leslie Co. 2 in. control valve) is situated between and fed from the two 250 gallon fiberglass head tanks on the raised platform. The head tanks are supplied from the three 1350 gallon fiberglass storage tanks shown on the right of the photograph. Under the raised platform are the components of the brine making system: a 36 in. Lixator (International Salt Co.) and a 400 gallon surge tank. Except

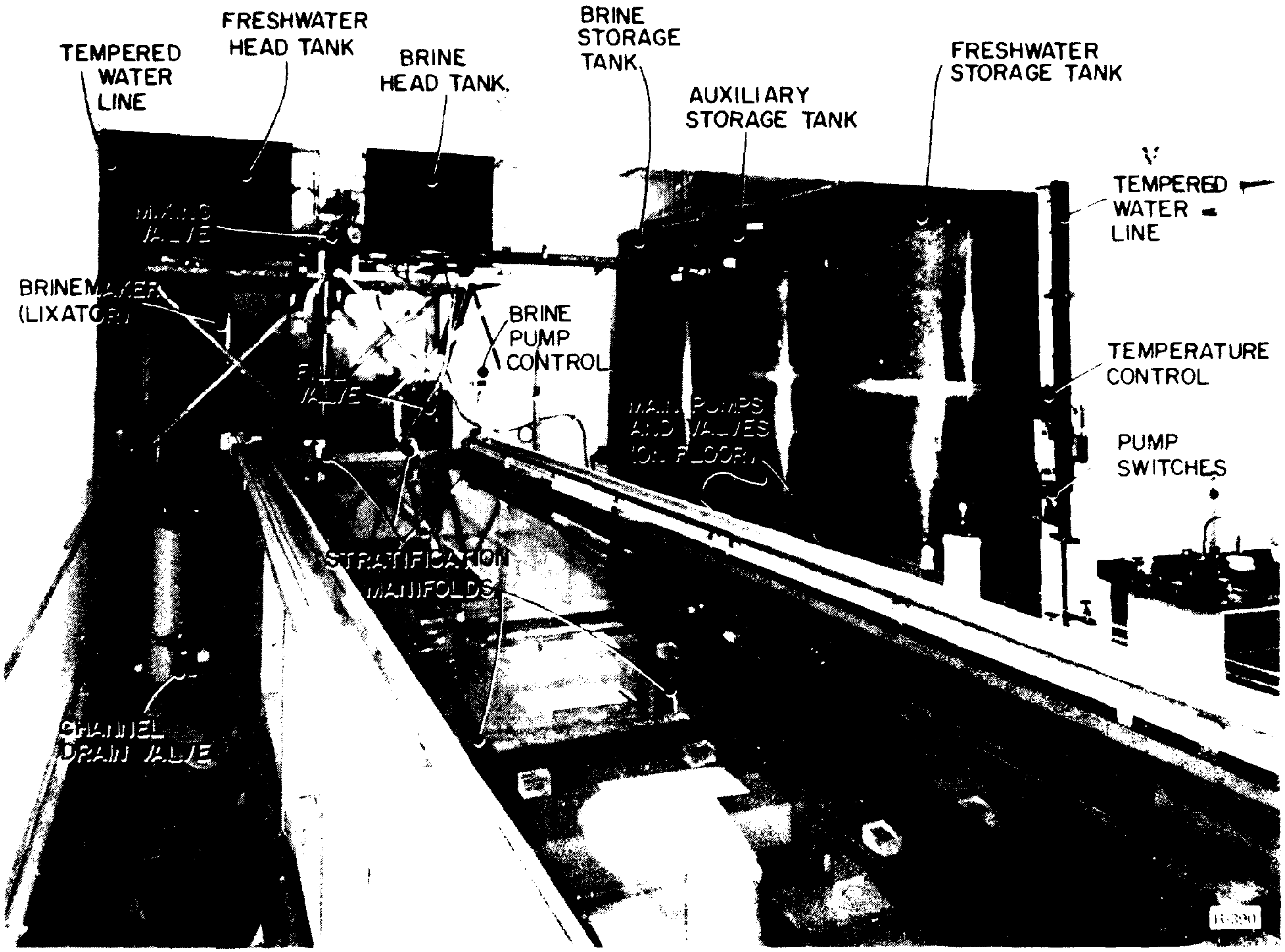

Fig. 4 — A photograph of the stratification system showing components of both the mixing system and the brine making equipment

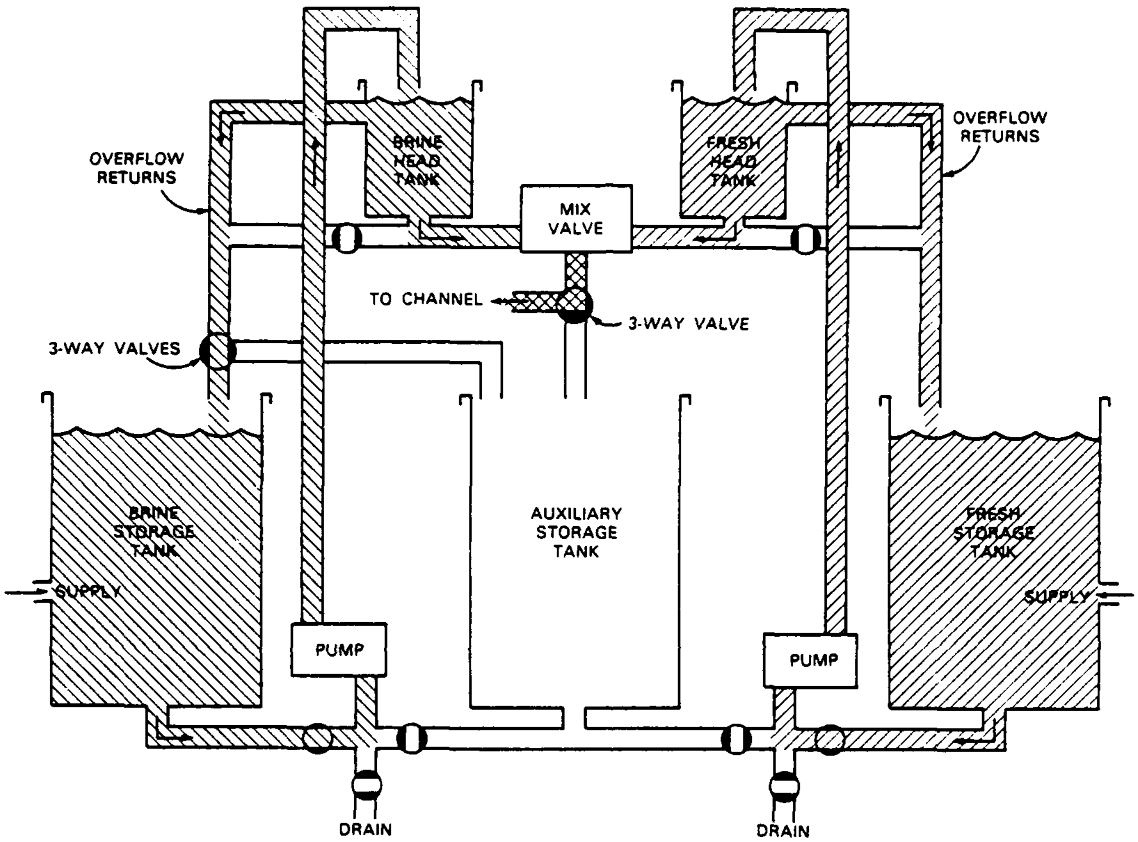

Fig. 5 — A schematic of the main features of the mixing system. Shaded areas indicate the nominal mixing process.

for the mixing valve all connecting pipes and fittings are plastic (PVC Schedule 80) to prevent corrosion. All valves are hand-operated, ball construction. The mixing system and the brine making system are discussed in more detail in the following paragraphs.

The mixing system A schematic of the mixing system is shown in Figure 5. In operation, water is continuously and separately pumped from the fresh water storage tank and the brine storage tank to the respective constant head tanks on either side of the mixing valve. The levels in the head tanks and thus the inlet pressures to the mixing valve are held constant by means of overflow standpipes. The overflow pipes return the excess water to the proper storage tank. The shaded sections of the schematic indicate this operation. The combined capacity of the three large storage tanks is less than the capacity of the towing channel so that replenishment is always required during the stratification process. A plot of the mixing valve performance is given in Figure 6.

Several alternate procedures which utilize the auxiliary storage tank to enhance operations are possible. The auxiliary tank can be used in place of or in parallel with either the freshwater or the brine storage tank. It is likely to be used in this way to increase the brine storage capacity. The valve settings that are required to achieve the desired combination are straightforward. The most common use of the auxiliary storage tank is as a source of brine precisely mixed at some uniform concentration less than 100 percent. Under these circumstances the auxiliary tank is filled as a result of an earlier mixing process between saturated brine and freshwater. Several three-way ball valves are located in the outlet line of the mixing valve and the constant head tank overflow lines to accomplish these operations. The proper valve settings are easily determined. The reason for having a precisely mixed unsaturated brine supply is to insure that enough of the mixing valve range is utilized to provide sufficient resolution even with relatively weak stratifications.

The density of the mixture delivered to the towing channel is determined by the position of a plug within the mixing chamber of the valve. This position is advanced from the 100 percent freshwater position by means of a stepper motor and mechanical actuator arrangement. The stepper motor pulses are derived from a flowmeter in the mixing valve outlet

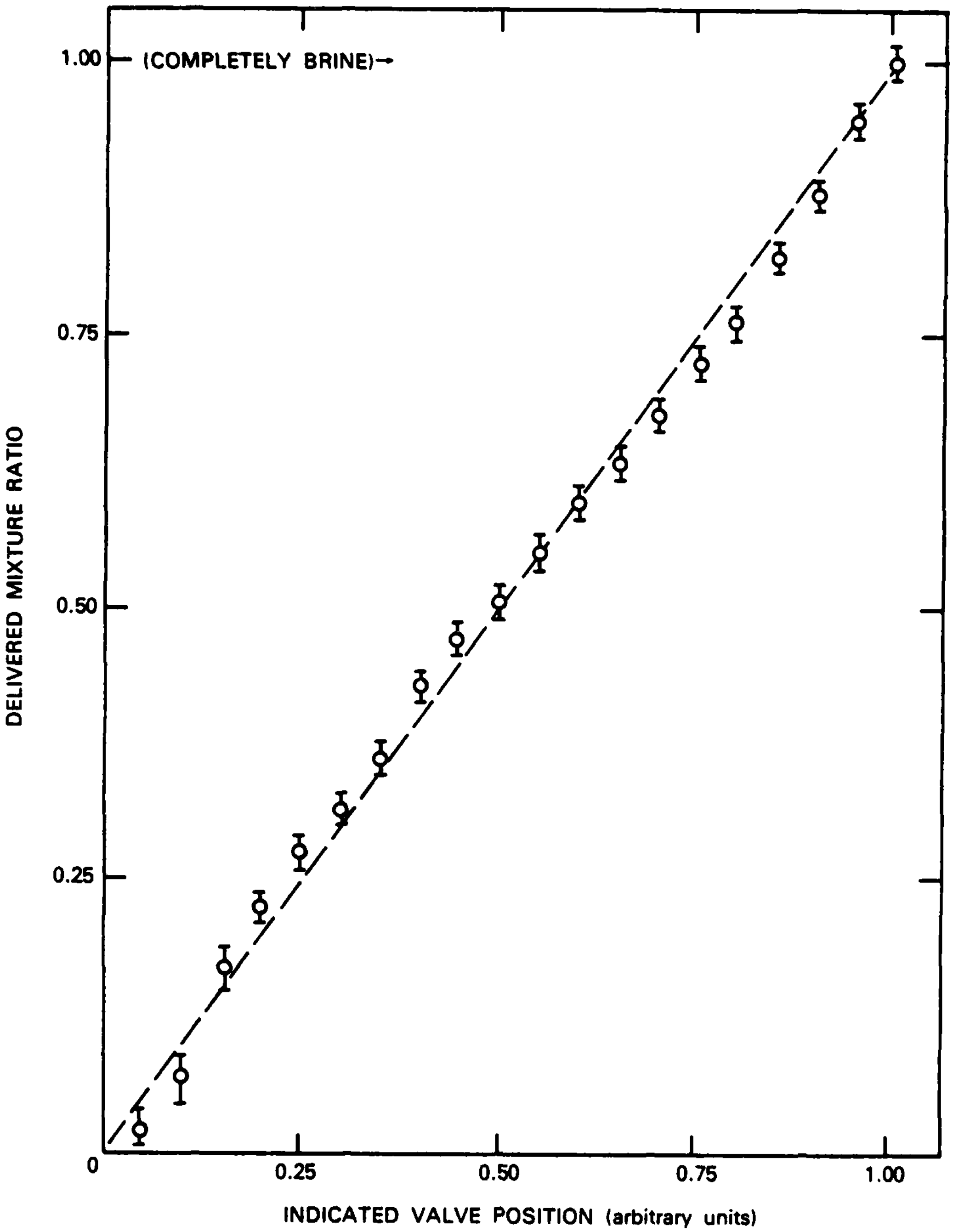

Fig. 6 — A calibration plot for the mixing valve

line. The flowmeter signal is an asynchronous digitial series where each pulse represents the passage of a certain volume of fluid. The signal processing for the stepper motor simply consists of a series of divide-by N digital counters which can be programmed by thumbwheel settings. Up to four pulse ratios can be programmed to correspond to different volume intervals or, equivalently, layers within the channel. Once set, the control unit will automatically fill the channel with up to four layers of different linear density profiles. The advantage of repeatability from one channel filling to another is evident. Any number of additional layers can be formed by resetting the control unit in batches less than the capacity of the channel. In this way virtually any stable density stratification can be generated using a piece-wise linear approximation and waiting for diffusion to "round-out" the profile.

The control unit also has several thumbwheel set points which activate relays for adjustable volume intervals. These can be used to activate other devices or processes for specified intervals when predetermined water levels are reached in the channel. Examples of activated devices are density profilers, mixture samplers, or dye injection valves to tag certain layers of fluid within the channel. A description of the control panel settings is included in the Appendix on Step-By-Step Operations.

The Brine maker The central component of the brine making system sketched in Figure 7 is the International Salt Co. Lixator. This unit produces 100 percent saturated and filtered brine at room temperature from tempered freshwater and bulk rock salt. The model employed in the present system produces 110 gallons of brine per hour and consumes nearly 300 lbs. of salt in that time. The Lixator has a capacity for about 2800 lbs. of rock salt. The saturated brine accumulates in an adjacent 400 gallon surge tank. If the level of brine in the surge tank reaches the water level within the Lixator a mechanical float valve ceases brine production. A pump at the outlet of the surge tank operates automatically to supply brine to the large brine storage tank. The pump is switched on if the level in the surge tank is sufficient (determined by level switches) and if the brine batch controller (Signet Model 302) indicates that a demand for brine exists. The batch controller compares the amount of brine delivered (measured by a flowmeter) to the amount requested by dial settings on the

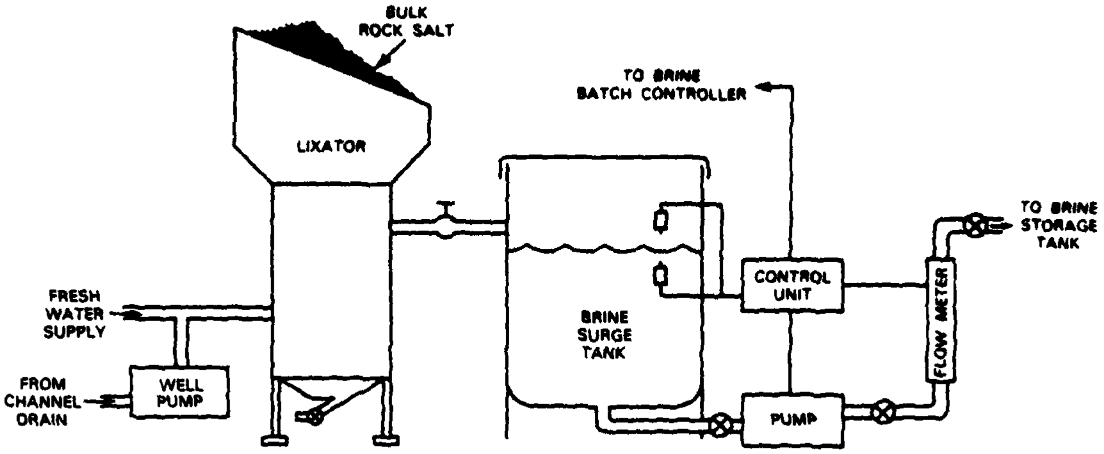

Fig. 7 — A schematic of the brine making system

front panel and operates the pump relays accordingly. Except possibly for the loading of additional bulk salt the system runs untended.

Since much of the salt is contained in the relatively untouched layers at the bottom of the channel, a capability for recycling this brine was added to the system. In the recycling process the freshwater inlet to the Lixator is switched to the towing channel drain by way of a shallow well pump. While this extends the fill-test-drain cycle signifigantly it can retrieve as much as two-thirds of the salt in a linearly stratified channel.

SUPPORT EQUIPMENT

In addition to the facility described in the previous sections a substantial array of instrumentation, data acquisition and processing systems, and other support equipment are available to the Marine and Environmental Hydrodynamics Laboratory. Several channels of hot film and laser doppler anemometry are available for the measurement of velocity. Density can be determined in a number of ways including conductivity probes, salimeters, and refractometers. A variety of pressure and force transducers along with signal conditioning units and multiple-port scanning valves permit measurement of very low level dynamics. Structural motions can be obtained using accelerometers or by remotely tracking objects with autocollimators. Still and motion photography equipment is available as is a staff of technical photographers.

Several systems for digitized data acquisition and processing are available including desktop minicomputers, FFT analyzers, measurement and control processors, and microprocessors. A capability for the acquisition and processing of digital video images exists in the laboratory to enhance the flow visualization analysis. There is a rapidly growing assortment of dyes and flow visualization techniques that range from common tracers to various light activated compounds.

SUMMARY

A salt stratified towing channel has been constructed at the Naval Research Laboratory in support of research programs in fluid mechanics. The primary impetus for the addition of this facility to the Marine and

Fig. 8 — Top view of the late wake coherent vortex pattern behind a towed sphere in a linearly stratified fluid. The photograph was taken long after the dyed turbulent wake had "collapsed" vertically.

Environmental Hydrodynamics Laboratory was the initiation of a basic research program concerning large-scale coherent motions in the turbulent wakes of bluff bodies. A typical photograph of the late-wake flow pattern behind a towed sphere is presented in Figure 8. The salient features of the facility are listed below.

The channel:

- 3 ft. deep x 4 ft. wide x 60 ft. long
- Clear acrylic walls and floor over 80 percent of the channel length
- One day fill-test-drain cycle

The towing system:

- Dual carriage cable drive (independent on/off)
- Extra drive pulleys/clutches for versatile towing configurations
- Common 3 Hp. variable speed D. C. motor drive
- 1-24 in./sec. speed range (±0.1% regulation)
- Low vibration levels

The stratification system:

- Automatic saturated brine production
- Automatic four layer stratification
- Programmable linear slope within layers
- Arbitrary stable density profiles
- Brine recycling

Support systems and equipment:

- Hot-film and laser anemometers
- Conductivity sensors, salomenters, and refractometers
- Pressure and force sensors
- Optical motion trackers
- Dyes and dye concentration sensors
- Still and motion photography
- Analog and digital video systems
- FFT analyzers
- A/D converters, Measurement and control processors
- Several minicomputers and desktop units.

ACKNOWLEDGMENTS

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Appendix - Step-By-Step Operation

Preparation In advance of a stratified towing experiment the large storage tanks must be configured and filled according to the volume requirements of the stratification. The configuration is set by opening or closing the appropriate valves located between the tanks at floor level. This determines which tanks will supply the two pumps that are also located between the storage tanks. Once the configuration is set it is important to insure that the two drain valves are closed and that both overhead three-way valves on the brine overflow return lines are set to return the excess water to the proper storage tank. Since the combined capacity of the three storage tanks is less than the capacity of the channel, it is always neccessary to replenish one or more of the storage tanks during the stratification process. Usually enough brine is produced and stored ahead of time so that replenishment occurs only on the freshwater side. The freshwater storage tank is filled or replenished from the supply line at the right of the tank. The inlet freshwater temperature is regulated to a value at or near ambient by adjustment of the tempered water control located on the column.

Saturated brine is produced and delivered in the desired quantity as follows. First the hopper is filled with bulk rock salt and the inlet supply line to the Lixator is opened.[1] After power is applied to both the brine batch controller and the brine pump unit (see Figure 4) the desired number of gallons of brine is entered via dial settings on the batch controller. To begin delivery, the batch controller is placed in the manual mode and the start button is pressed. The system will shut down when the specified volume of brine is transferred to the brine storage tank which will take about one hour for every 100 gallons. If a power outage occurs, the delivered brine count is lost and upon resumption of power the system waits to start the cycle again.

Channel stratification The first step in stratifying the channel is to establish the proper settings on the mixing valve control panel, shown in Figure A1. The various thumbwheel inputs must be set to correspond to the

[1] The operations for reclaiming unsaturated brine from the towing channel are described later in the appendix.

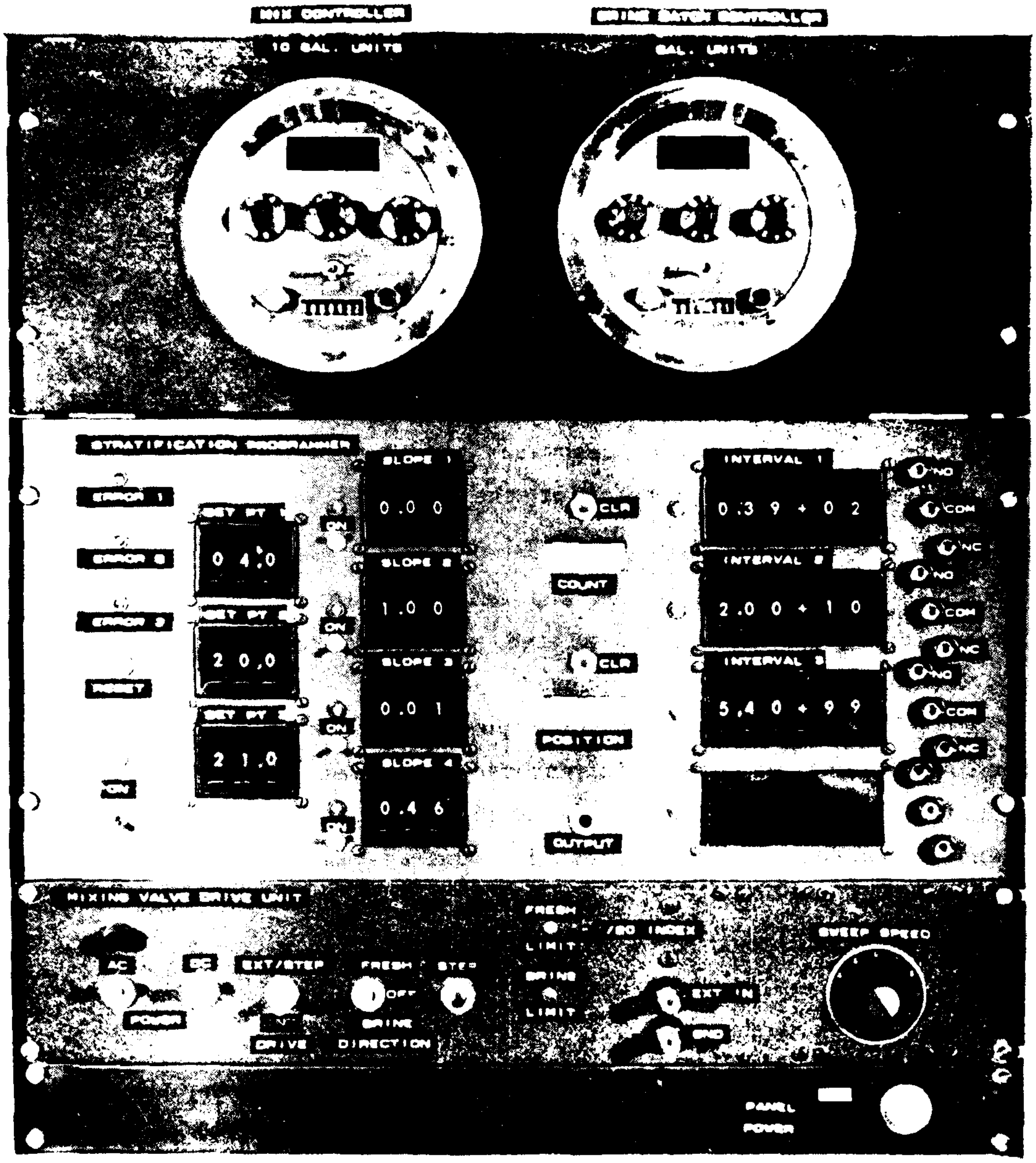

Fig. A1 — Photograph of the stratification system control unit

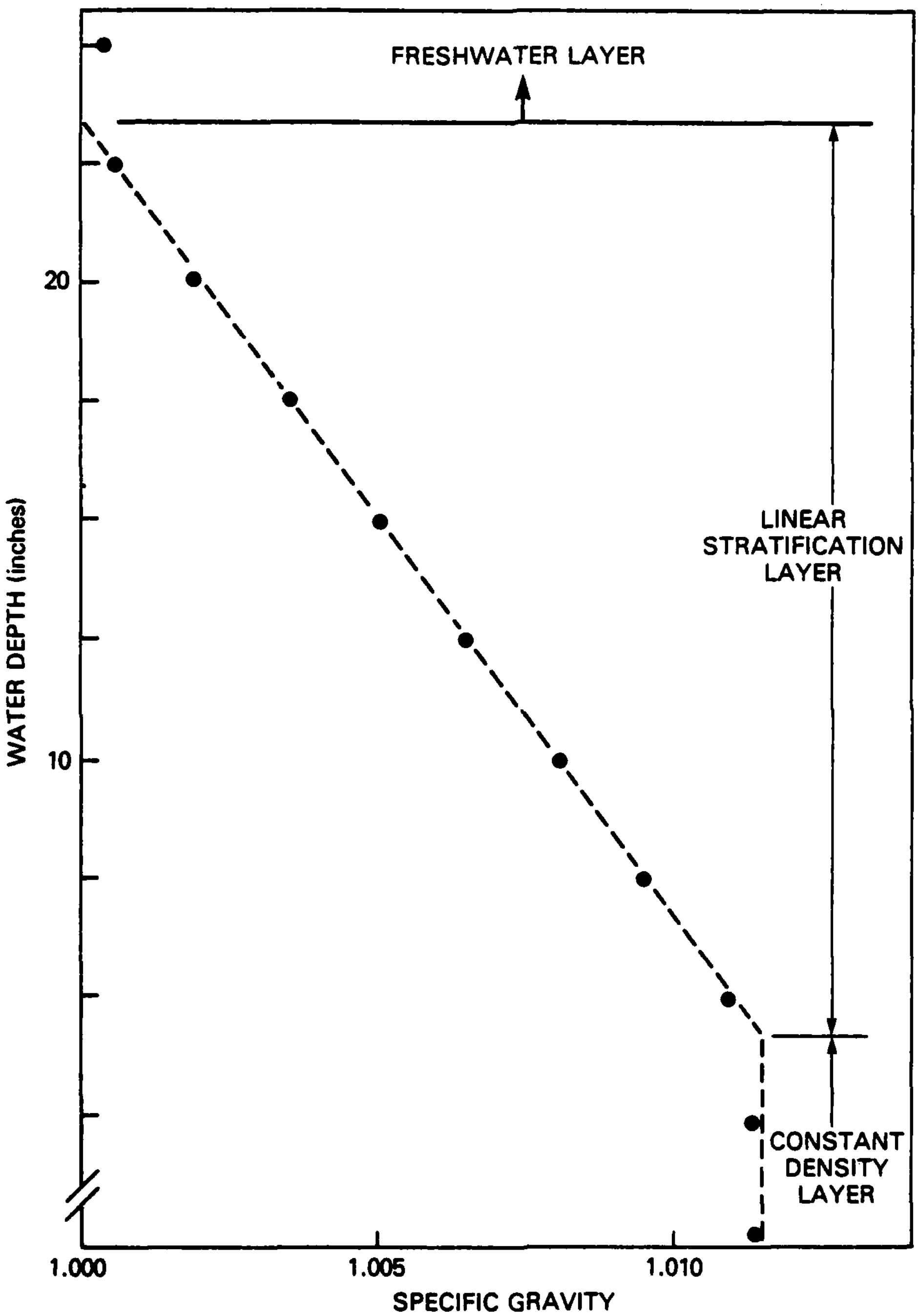

Fig. A2 — A typical density profile measured in the channel prior to a towing experiment

desired number and thicknesses of the layers in the towing channel. The slope of the density variation in each fluid layer must be selected as well. The units for the layer set points correspond to the display of the stratification batch controller and are expressed in tens of gallons, i.e., total channel capacity = 540 • ten gallons). Ten gallons of mixture delivered to the channel are equivalent to a depth increment of about 1/16 inch.

The filling cycle is initiated by first closing the two drain valves on the head tanks and then powering the two pumps. While the head tanks are filling, the mixing valve is returned to the "home" position (100 percent freshwater) by manual operation of stepper motor drive. The "home" position is achieved by taking the valve to the upper limit as indicated by the freshwater limit light. When the head tanks are both overflowing to their respective storage tanks the stratification batch controller is placed in the manual mode and the start button is pressed. The filling process can be interrupted at any time by closing the manifold inlet valve and turning off the pumps. The outlet valve on the freshwater head tank should also be closed to preclude an exchange of fluid between head tanks. If the AC power is maintained, then the process can be resumed by simply starting the pumps and reopening the valves. If the AC power is interrupted the system ceases operation even if power is reapplied.

Several other features of the system need to be mentioned. The terminal count on the batch controller can be set for values less than channel capacity so that virtually any number of layers can be formed. The three contact closure relays can be set to close at any value of the system count and to remain closed for up to 99 system counts. The final stratification can be adjusted "up" and "down" in the channel by adding or withdrawing fluid at the bottom and replenishing as needed in the freshwater above. A sample of a three-layer stratification in the channel is shown in Figure A2.

Tow system operation - Although the towing system operates in either direction it has become customary to run experiments from left to right or equivalently from the drive system end of the channel toward the stratification equipment. The controls and equipment are labelled

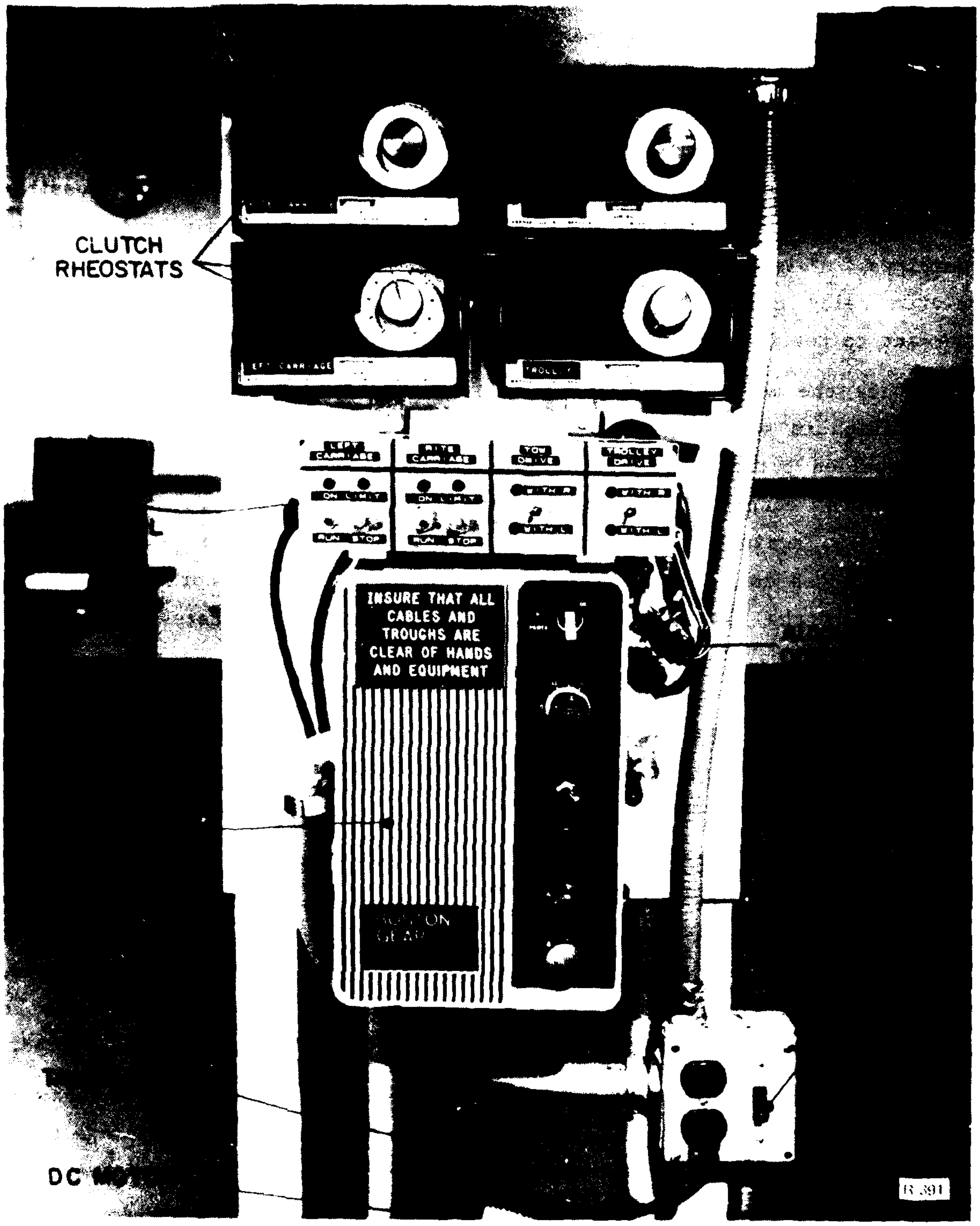

Fig. A3 — Photographs of the towing system control unit

accordingly and this description follows that convention. The main power switch for the D.C. motor is on the front of the Ratiotrol control box while the main switch for the electromagnetic clutches and their control relays is in the junction box at the lower right (see Figure A3). The D.C. motor can be started and the tow speed adjusted without engaging any of the drive cables. The speed adjustment knob indicates the speed as a percentage of the maximum speed (approximately 24 in./sec.). The relay control box allows the two carriages to be started/stopped independently. It is also possible to start/stop either auxiliary drive pulley in tandem with either carriage. This is accomplished by the toggle switches on the right of the clutch relay control. The four clutch rheostats control the amount of current to the individual clutches.

Once the motor is running at the desired speed and the correct drive combination is set, the first or right-hand carriage is started by pressing the labelled button. A green light indicates engagement of the cluch (if the rheostat current is sufficient) whereas a red light indicates that the carriage is against its limit switch at either end of the channel. The limit switches can be momentarily by-passed using the appropriate button on the side of the towing channel. The second carriage operates in the same manner. Both carriages will stop at the end of travel in both directions. If one carriage encounters the other in its path the disengaged carriage will be pushed along until both reach their limits. Emergency stop switches, which disengage all clutches immediately, are located at ten foot intervals along the channel.

<u>**Draining and recycling**</u> The towing channel is emptied into the floor drain by opening the 2 inch ball valves at each end of the channel. If the brine in the bottom of the channel is to be recycled, the 1 inch ball valve on the drain line nearest the stratification system is opened instead. After power is applied to the well pump, the brine making system can be operated as before except that the consumption of bulk salt will be reduced.

The two constant head tanks can be emptied back to the storage tanks by opening the valves in the outlet lines of the head tanks. The storage tanks can be almost completely drained into the sewer system by valves between the storage tanks at floor level.

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